BETHEA COMPANY, INC.
BIRMINGHAM, ALABAMA

AN INTERIM REPORT ON SUSPENSION ASSEMBLIES FOR EHV USE

June 1, 1962

NO. 33

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BETHEA ENGINEERING REPORT NO. T-6206-13

FOR: Mr. R. L. McCoy

SUMMARY

Electric Utilities establish transmission line parameters based upon a number of economic and engineering considerations. It is assumed by the Utilities that once voltage, conductor size, conductor configuration, and the like are determined there will be available the mechanical means for carrying out the plans so made.

It is well recognized that as transmission line voltages increase the mechanical features of construction must be modified to allow for special problems occurring at higher voltages. Such problems include losses due to corona and radio noise associated with the corona discharge.

In its high voltage work Bethea Company has aimed at developing for the Utilities the most economical suspension assemblies that will fulfill the requirements which the Utility has established for a particular circumstance.

In its investigations Bethea Company determined to fully investigate its belief that most high voltage suspension assemblies used in the past were overly elaborate and subject to the various mechanical problems, such as vibration failure, associated with overly elaborate devices. Therefore, Bethea Company commenced its work determined to begin in each case with the simplest types of devices and progress to more elaborate devices only when test results demanded it.

As a result of its study Bethea Company has determined that very simple devices will give excellent results. In addition it has been determined that in many instances no special suspension devices are required if reasonable care is followed in the design of standard suspension assembly components.

PROCEDURE

It was determined that in each case the most direct approach would be to test full scale unshielded assemblies and then to progressively modify these assemblies as the tests progressed. Unsuccessful or unbeneficial modifications were eliminated as test results indicated.

In every case tubing of appropriate size was used to simulate the field of the conductor with its armor. Various numbers of insulators and various types of assemblies were tested as indicated in the results.

Only those results of immediate interest are shown. Those shown represent only a fraction of the tests run. The balance either represent unsuccessful designs or tests which are continuing.

All tests were conducted under the conditions spelled out in NEMA-107 except that a 1407 micro micro farad capacitor was used for practical reasons instead of the 2500 micro micro farad capacitor. Work by others has shown that such a substitution would introduce no serious errors. See Bibliography, Reference No. 6.

All tests were conducted at either Mississippi State University in Starkville, Mississippi or at General Electric Company in Baltimore, Maryland. There was excellent correlation between results obtained at the two different test locations. In work by others a good agreement between laboratory test data and field test data has been found. See Bibliography, Reference No. 4.

In all cases the data was plotted without attempt to adjust for background radio noise attributable to the test equipment. This was done in the absence of any accepted mathematical means of making such an adjustment. In actual fact, however, in some cases the limiting factor was the critical voltage of the test equipment and not the assembly being tested. Such cases will be reinvestigated upon further modification of the test equipment.

See Appendix II for curcuit diagram and typical physical set up.

TEST CRITERIA

1. Corona Limitations.

It was assumed that visible corona discharge from the suspension hardware was not critical in itself except as it related to radio noise. However, it was felt that visible corona around the insulator pins would be disqualifying due to the belief that such corona will accelerate corrosion in the highly stressed insulator pin area. Therefore on each curve an "X" will indicate the voltage at which visible insulator corona occurs. Where no "X" is shown no visible corona occurred on the insulators within the range of the curve shown.

2. Radio Noise Limitations.

In the absence of any established maximum acceptable radio noise level it is necessary to decide more or less arbitrarily what the maximum noise level shall be for a suspension assembly. It is the opinion of Bethea Company that a limit of 100 microvolts is a conservative level for safe operation. This noise level should give suspension assemblies with performance superior to many high voltage lines now in satisfactory operation as has been determined by laboratory testing of assemblies that are duplicates of those now on the line. A good example of such a relationship may be found in Bibliography Reference No. 4 although the geographical conditions shown in that reference might not be typical for all utilities. Our tests have indicated that a measured noise level on the suspension assemblies in the referenced installation might be expected to be in the neighborhood of 150 - 175 microvolts yet operation has been satisfactory.

3. Altitude Effect.

No attempt is made on the graphs to adjust for altitude effects. A basis for such adjustments may be found in the reports on Leadville Project, Bibliography, Reference 5.

4. Weather Effect.

No attempt has been made to adjust data for weather effect since experience would indicate that a maximum acceptable radio noise level of 100 microvolts in the laboratory would give satisfactory results on the line under conditions of inclement weather. See Bibliography, Reference No. 4.

5. Technical Responsibility

As noted, these tests were performed at Mississippi State University and General Electric Company in Baltimore. However, all plotting, correlation, and interpretation of data is by Bethea Company and represents solely the opinions of that company.

DATA SECTION
FOREWORD

This data is divided generally into sections as follows:

I. Variations in Unshielded Suspension Assemblies - Single String Insulators.

Chart I - Variations in conductor sizes - Single Conductor.
Chart II - Variations in conductor sizes - Two Conductor Bundle.
Chart III - Variations in number of conductors and in number of insulators.
Chart IV - Variations in number of insulators - Single Conductor.

II. Results of adding Simple Shielding and Grading Devices - Single String Insulators.

Chart V - Substitution of spherical nuts for regular hex nuts on suspension clamps - Single Conductor.
Chart VI - Substitution of spherical nuts for regular hex nuts on suspension clamps - Two Conductor Bundle.
Chart VII - Addition of spherical nuts and spherical shields on a Two Conductor Bundle.
Chart VIII - Addition of spherical nuts and spherical shields on a Single Conductor.

III. Investigation of "V" String Suspension Assemblies.

Chart IX - Addition of spherical nuts and spherical shields to "V" string suspension assembly - Two Conductor Bundle - 1 3/4" Conductor.

Chart X - Addition of spherical nuts and spherical shields to "V" string suspension assembly - Two Conductor Bundle - 2 1/4" Conductor.

IV. Bibliography and Circuit Diagrams.

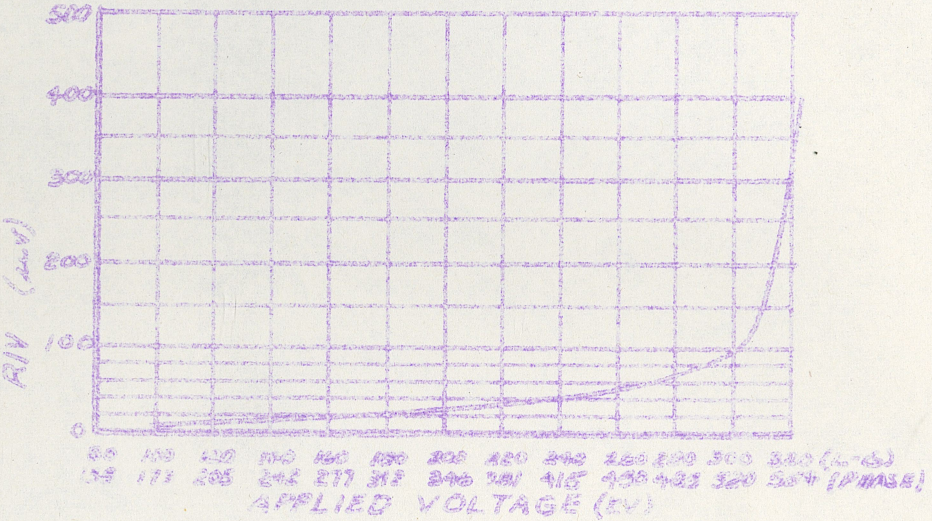
Special Note: There was no absolute basis for the right or wrong number of insulators to use in the various tests. It was initially decided to use the approximate number of insulators which a customer might use for the most probable voltage class for a particular assembly. Some of the assemblies tested considerably better than was anticipated in setting up the test sequences. As a result some of the assemblies, for absolutely optimum results, should be retested with a greater number of insulators. For example, the assembly in Chart VII with 16 insulators and the assembly in Chart VIII with 20 insulators both tested satisfactorily at a level well in excess of that originally anticipated and are actually handicapped by the relatively small number of insulators used.

Bethea Company recommends that the data included in this brochure be used as a general guide only and that specific assemblies be tested where this data is not directly applicable to the assembly in question. We will be happy to cooperate in any such tests required.

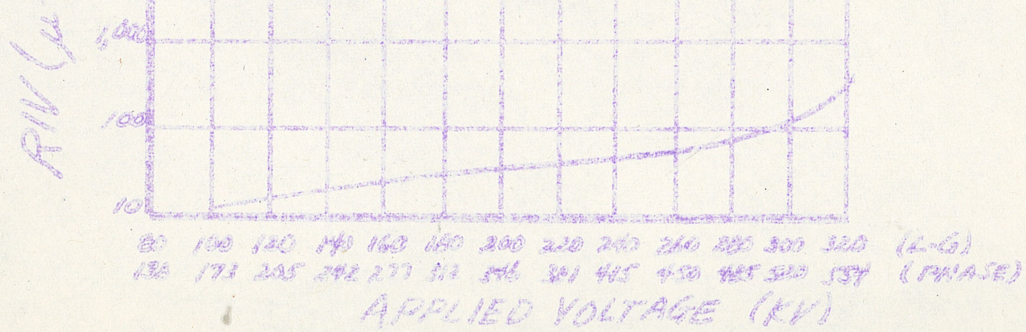
NOTE: The spherical nuts and spherical shield assemblies used in these tests are covered by pending patent applications.

CAUTION

All RIV Curves in this folder are plotted on plain Linear graph paper. Many equivalent curves found in the literature are plotted on Semi-Logarithmic graph paper. The physical appearance of the same curve plotted on the two types of paper will be very different and casual comparisons of curves should take this into account. Bethea Company feels that the linear plotting of RIV Curves more truly depicts the abrupt increase in RIV at the critical voltage than does the use of Semi-Logarithmic Scales. Shown below are identical curves plotted to the two different scales.



LINEAR PLOT



SEMI-LOG PLOT

NOTE

Charts IX-A, IX-B, and X represent tests on "V" String Assemblies. In some instances, as shown on the data, insulators were attached to the yoke with "Y" Socket-Clevises. In other instances connections were made with standard socket-clevises. The difference in performance between these two types of fittings is very marked and should be taken into account in planning.

Each chart shows in red the type fitting used.

CHART I

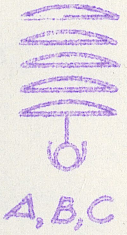
RADIO INFLUENCE VOLTAGE CHARACTERISTICS
OF
SUSPENSION ASSEMBLIES
(Unshielded & Single Conductor)

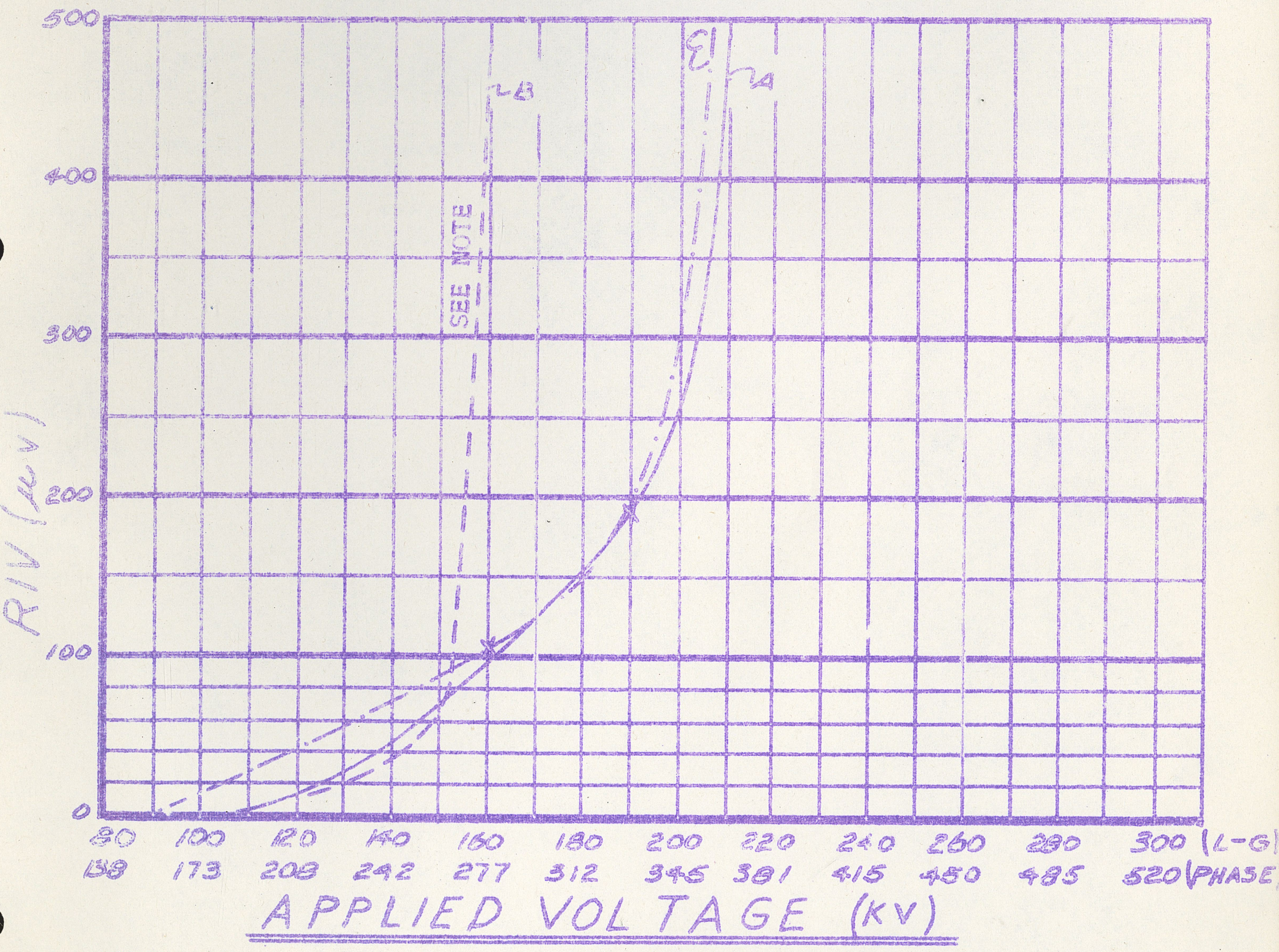
INSULATORS: 16 - 10" x 5" Socket Type Suspension

CURVE A:
CLAMP: Standard ASC-10-S
CONDUCTOR: 2 1/4" O.D. Tubular (Equivalent 954 - 54/7 ACSR with tapered rods)

CURVE B:
CLAMP: Standard LS-9-S
CONDUCTOR: 2" O.D. Tubular

CURVE C:
CLAMP: Standard LS-7-S
CONDUCTOR: 1 3/4" O.D. Tubular





NOTE: The apparent discrepancy in position of Curve "B" was due to excessively long U-Bolts in the clamp. Corona started on exposed U-Bolt threads at a very low level. There was less than 1/4" exposed threads for Curves "A" and "C".

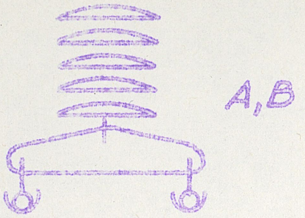
CHART II

RADIO INFLUENCE VOLTAGE CHARACTERISTICS
OF
SUSPENSION ASSEMBLIES
(Unshielded Bundled Conductor)

INSULATORS: 20 - 10" x 5" Suspension Insulators

CURVE A:
CLAMP: Standard LS-7-C
CONDUCTOR: Two 1 3/4" Horizontal Tubular Bundle 18" Spacing.

CURVE B:
CLAMP: Standard ASC-10-C
CONDUCTOR: Two 2 1/4" Horizontal Tubular Bundle 18" Spacing.



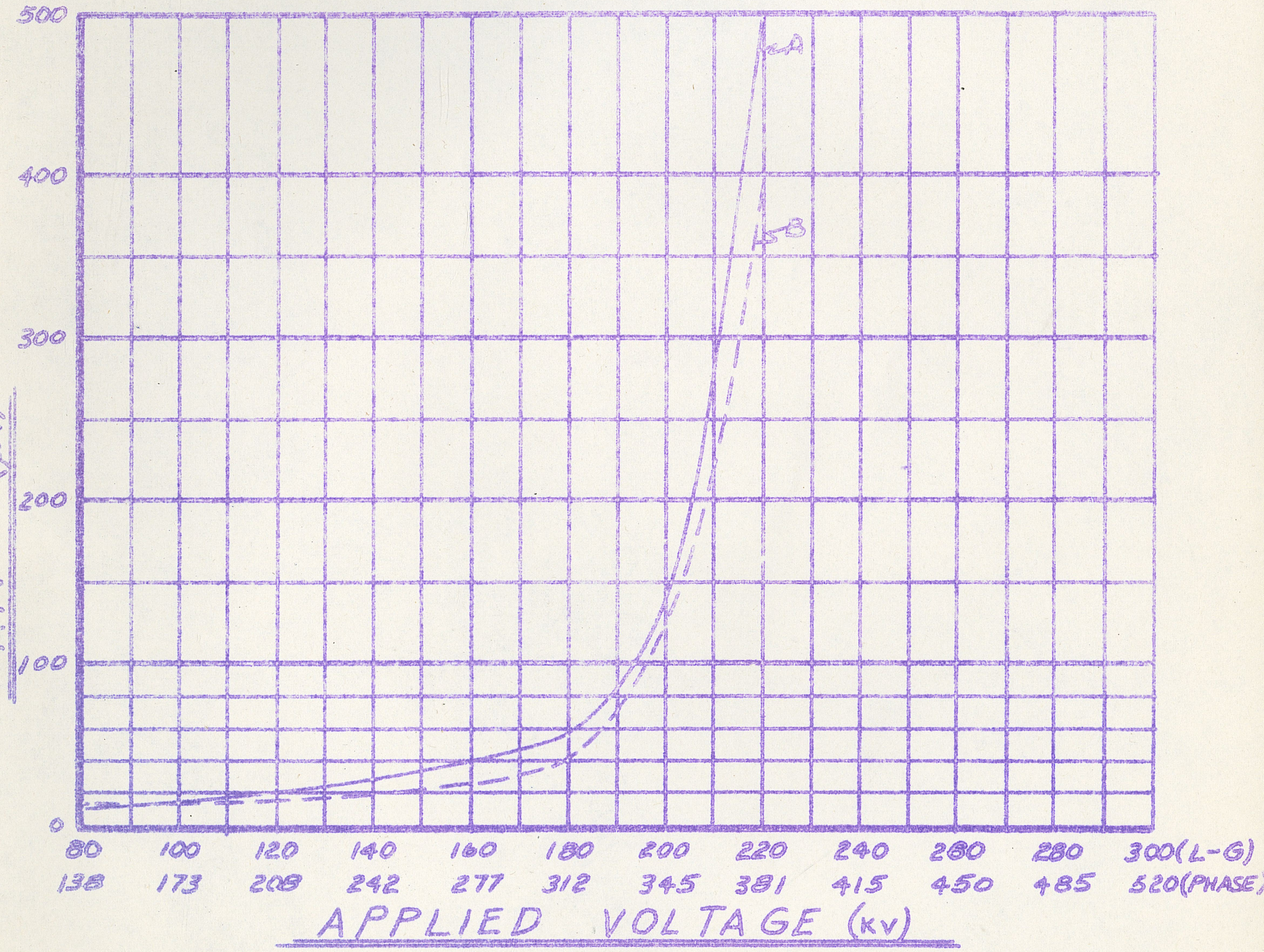


CHART III

RADIO INFLUENCE VOLTAGE CHARACTERISTICS
OF
SUSPENSION ASSEMBLIES
(Unshielded Bundle Conductors)

INSULATORS: (See Below)

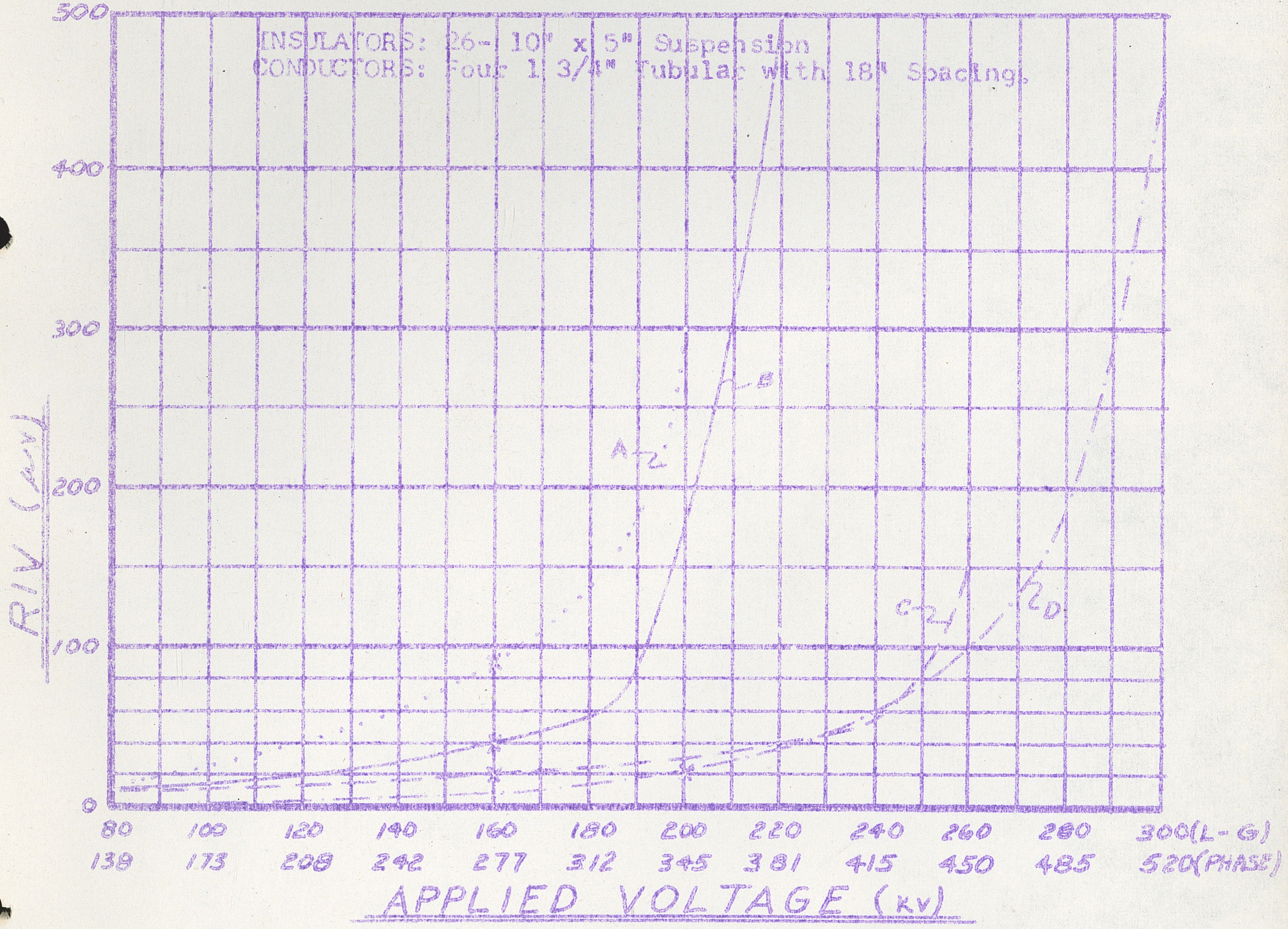
SEE ATTACHED SHEET
FOR TEST DIAGRAMS.

CURVE A: INSULATORS: 16 - 10" x 5" Suspension
CLAMP: Standard LS-7-S
CONDUCTOR: 1 3/4" O.D. Tubular (SINGLE CONDUCTOR)

CURVE B:
CLAMPS: Two Standard LS-7-C
INSULATORS: 20 -10" x 5" Suspension
CONDUCTOR: Two 1 3/4" Horizontal Tubular 18" Spacing.

CURVE C:
CLAMPS: Three Standard LS-7-C
INSULATORS: 26 - 10" x 5" Suspension
CONDUCTORS: Three 1 3/4" Triangular Tubular with 18" Equilateral Spacing.

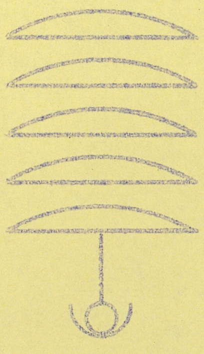
CURVE D:
CLAMPS: Four Standard LS-7-C
INSULATORS: 26- 10" x 5" Suspension
CONDUCTORS: Four 1 3/4" Tubular with 18" Spacing.



NOTE: Corona in these tests was observed by means of high powered, night vision binoculars. The low values shown indicates that the pickup of visual corona is dependent upon the sensitivity of the viewing device. Simple visual observation, as was used in other tests would have resulted in considerably higher corona onset levels.

CHART III

TEST DIAGRAMS



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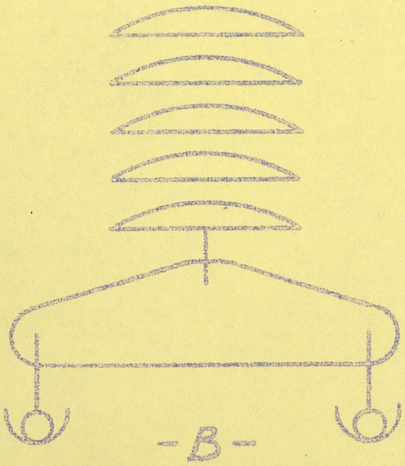

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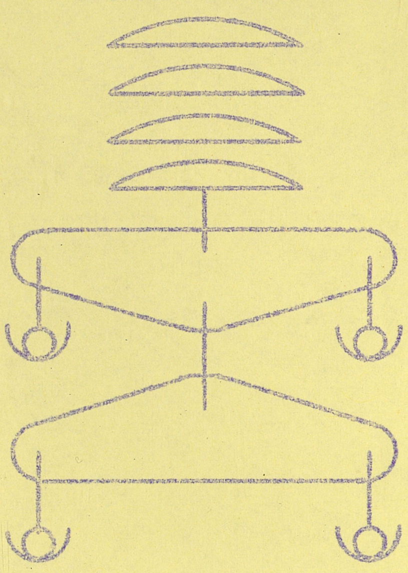

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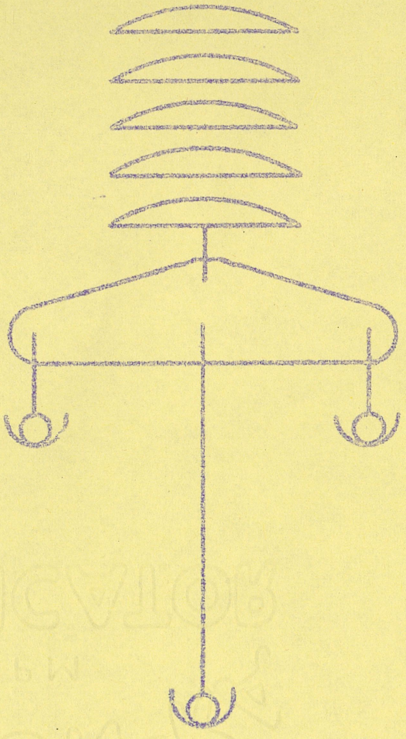


-C-

CHART IV

RADIO INFLUENCE VOLTAGE CHARACTERISTICS OF UNSHIELDED SUSPENSION ASSEMBLIES

(Effect of Change in Number of Insulators)

CLAMPS: Standard ASC-10-S
CONDUCTOR: Single 2 1/4" Tubular

CURVE A: 13- 10" x 5" Suspension

CURVE B: 16- 10" x 5" Suspension

CURVE C: 20- 10" x 5 3/4" Suspension

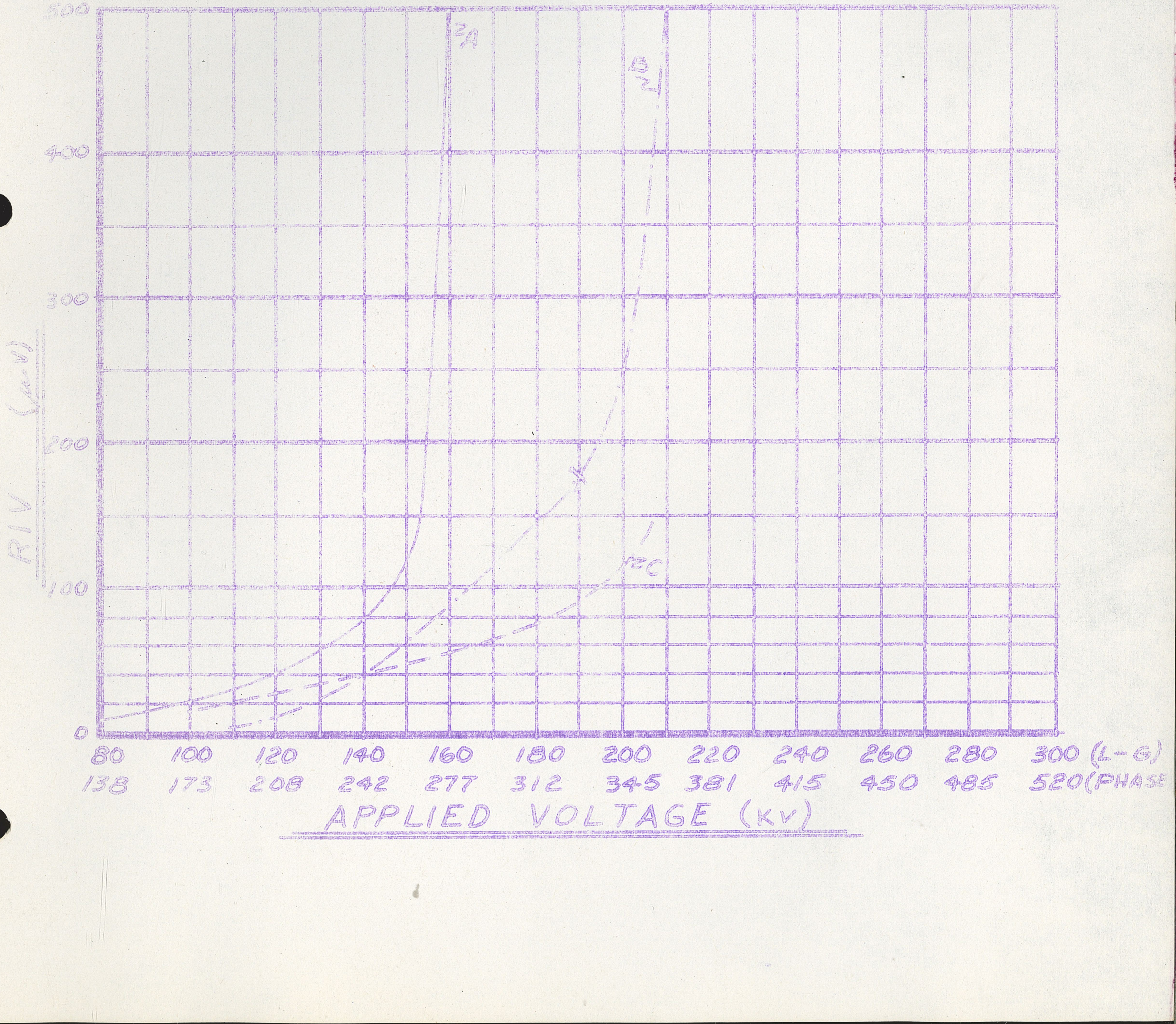
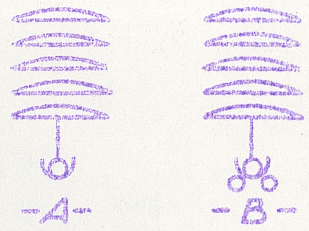


CHART V

RADIO INFLUENCE VOLTAGE CHARACTERISTICS
OF
SUSPENSION ASSEMBLIES
(Effect of Spherical Nut on U-Bolts)
(Single Conductor)



CLAMPS: ASC-10-S
INSULATORS: 16- 10" x 5" Suspension
CONDUCTOR: 2 1/4" Tubular (Single)

CURVE A: Plain Clamp Standard Hardware

CURVE B: Plain clamp except with 1 3/4" Dia. Spherical Nuts instead of hex nuts.

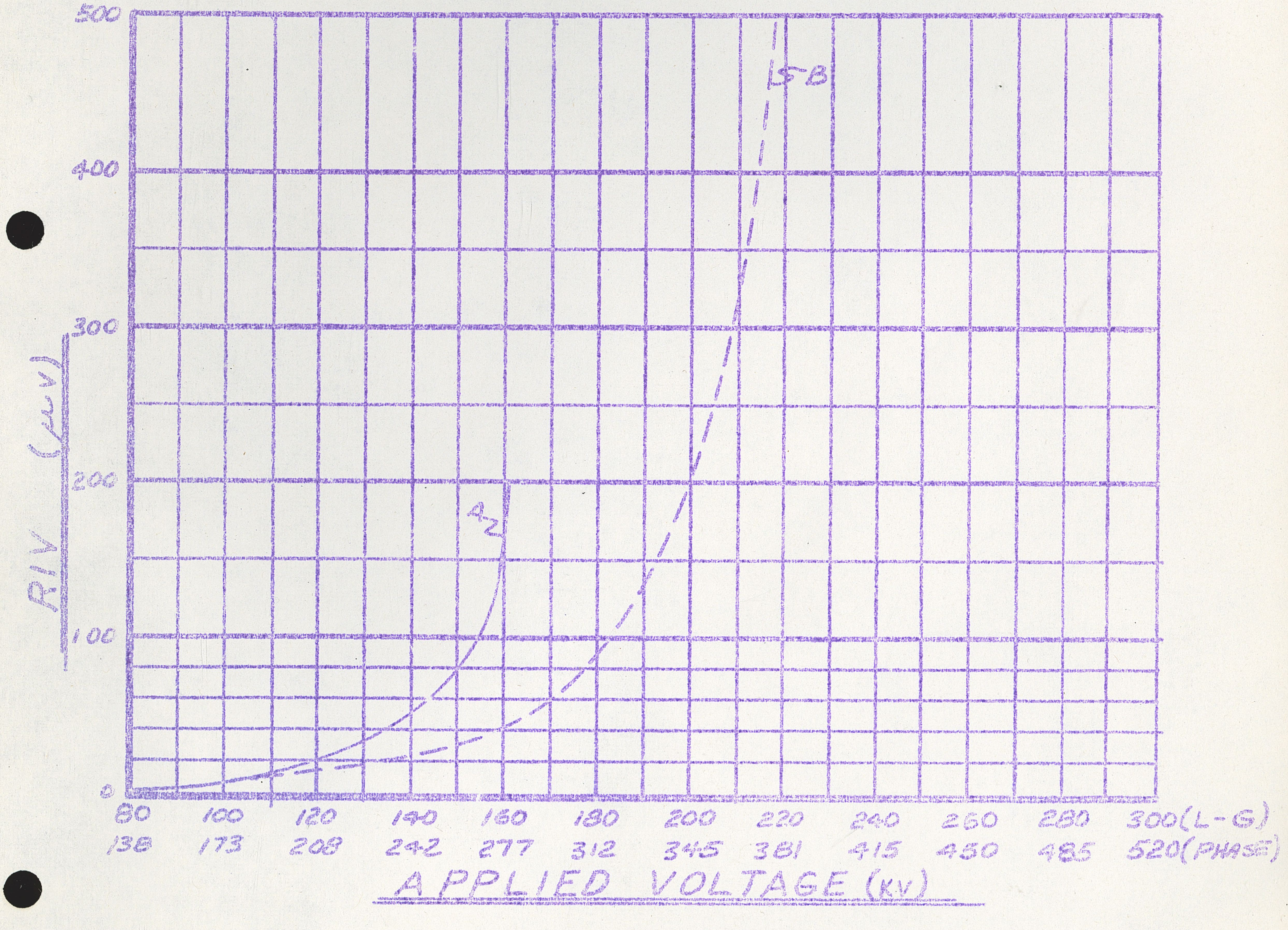


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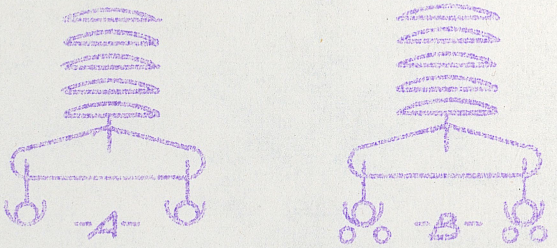
CHART VI

RADIO INFLUENCE VOLTAGE CHARACTERISTICS
OF
SUSPENSION ASSEMBLIES
(Effect of Spherical Nuts on U-Bolts)
(Two Conductor Bundle)

CLAMPS:	ASC-10-C
INSULATORS:	20- 10" x 5" Suspension
CONDUCTORS:	Two 2 1/4" Horizontal Tubular Bundle 18" Spacing.
CURVE A:	Plain Clamp Standard Hardware
CURVE B:	Plain Clamp except with 1 3/4" Dia. Spherical Nuts instead of hex nuts.



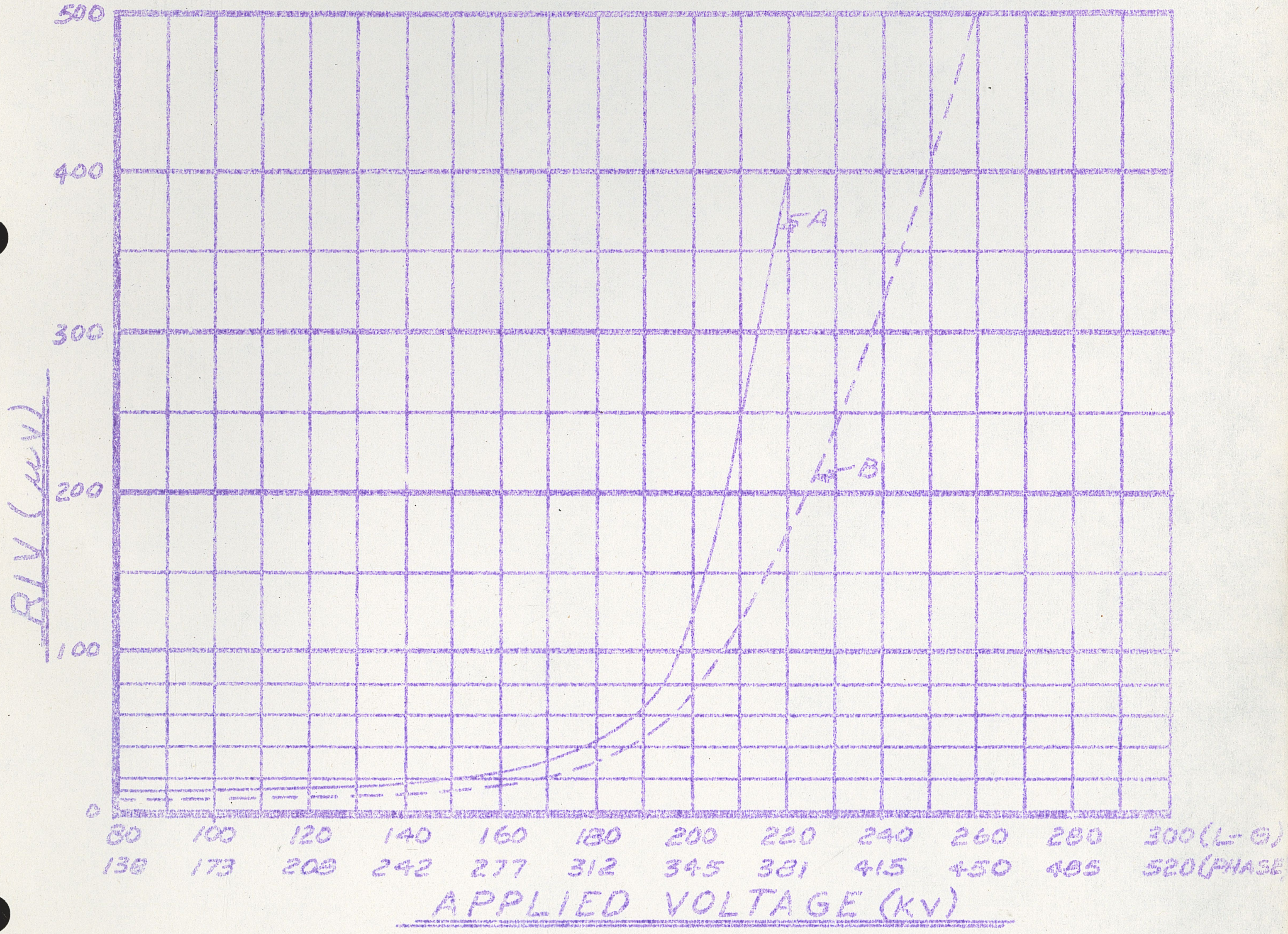


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CHART VII

RADIO INFLUENCE VOLTAGE CHARACTERISTICS
OF
SUSPENSION ASSEMBLIES

(Development of A Good 345 KV Suspension Assembly)

CLAMPS:	LS-7-C
CONDUCTORS:	Two 1 3/4" Tubular Horizontal 18" Spacing.
INSULATORS:	16- 10" x 5" Suspension
CURVE A:	Plain Clamps
CURVE B:	Plain Clamps with 1 3/4" Dia. Sphere Nuts on U-Bolts.
CURVE C:	Sphere Nuts and Spheres on tips of yoke plate.

SEE ATTACHED SHEET
FOR TEST DIAGRAMS.

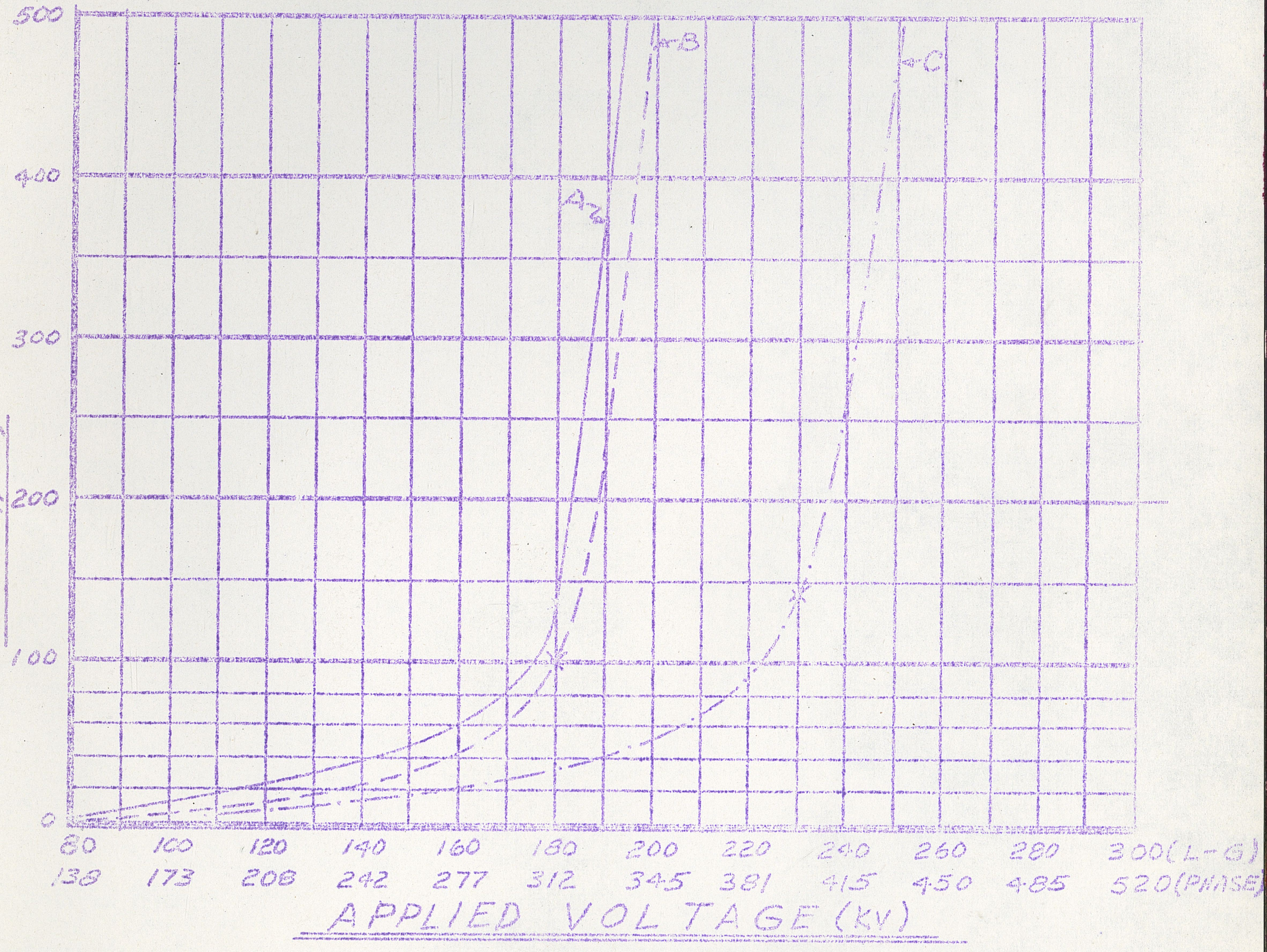
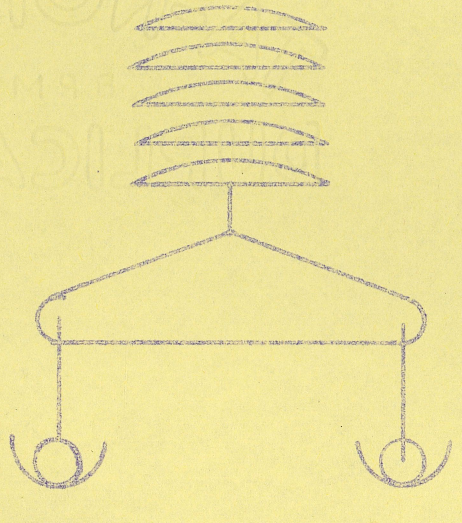


CHART VII

TEST DIAGRAMS



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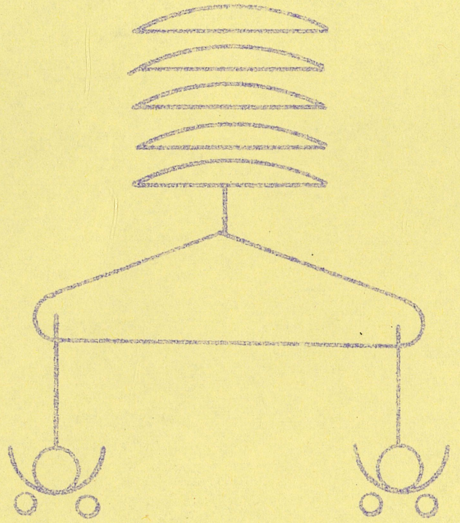

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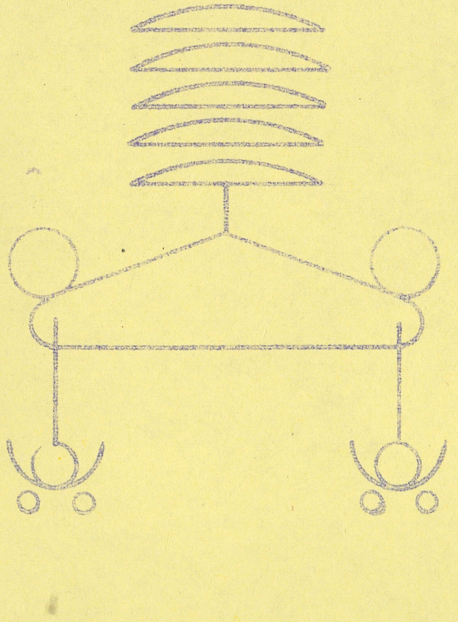

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CHART VIII

RADIO INFLUENCE VOLTAGE CHARACTERISTICS
OF
SUSPENSION ASSEMBLIES

(Large Spherical Shields Single Conductor)

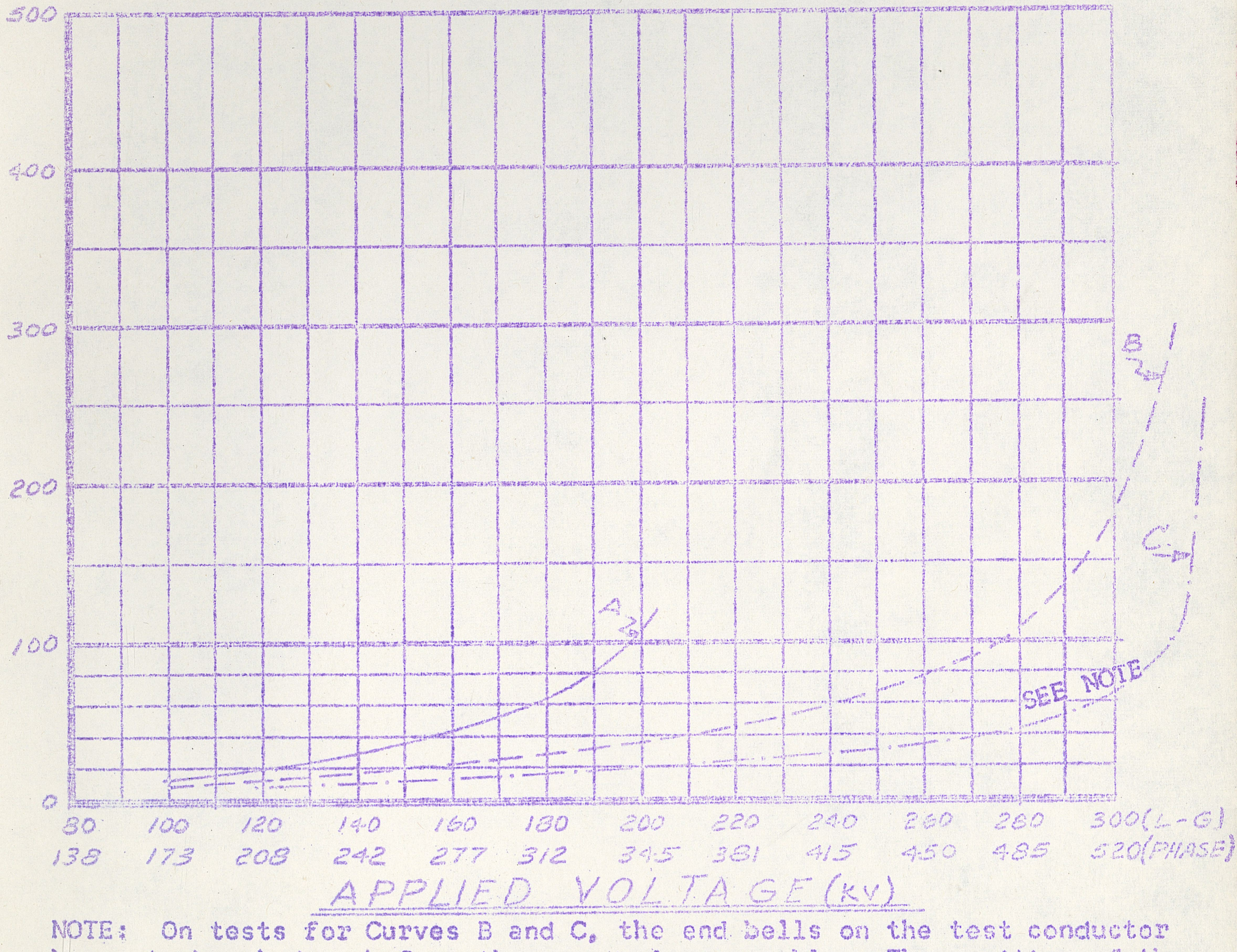
CLAMPS: ASC-10-S
CONDUCTOR: 2 1/4" Tubular
INSULATORS: 20- 10" x 5 3/4" Suspension

CURVE A: Plain Clamp (No Shielding)

CURVE B: Plain Clamp with 6 inch diameter spherical shields.

CURVE C: Plain Clamp with 1 3/4" Dia. Spherical Nuts and 6" Dia. Spherical Shields.

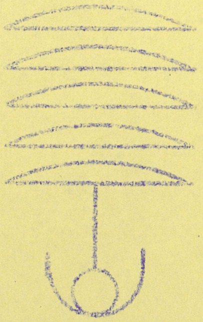
SEE ATTACHED SHEET FOR
TEST DIAGRAM.



NOTE: On tests for Curves B and C, the end bells on the test conductor began to break down before the suspension assembly. The position of the breaks in these curves are effected very substantially because of this.

CHART VIII

TEST DIAGRAMS



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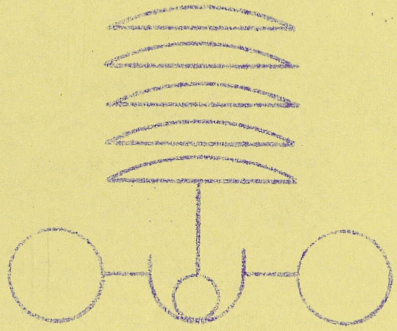

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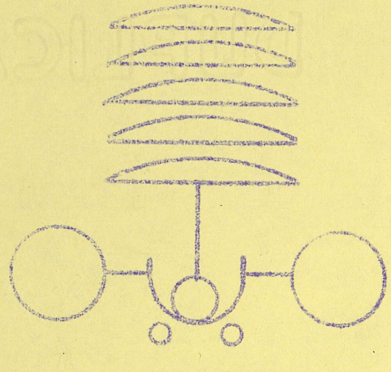

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CHART IX-A

RADIO INFLUENCE VOLTAGE CHARACTERISTICS
OF
SUSPENSION ASSEMBLIES

("V" String Bundle And Large Spherical Shields)

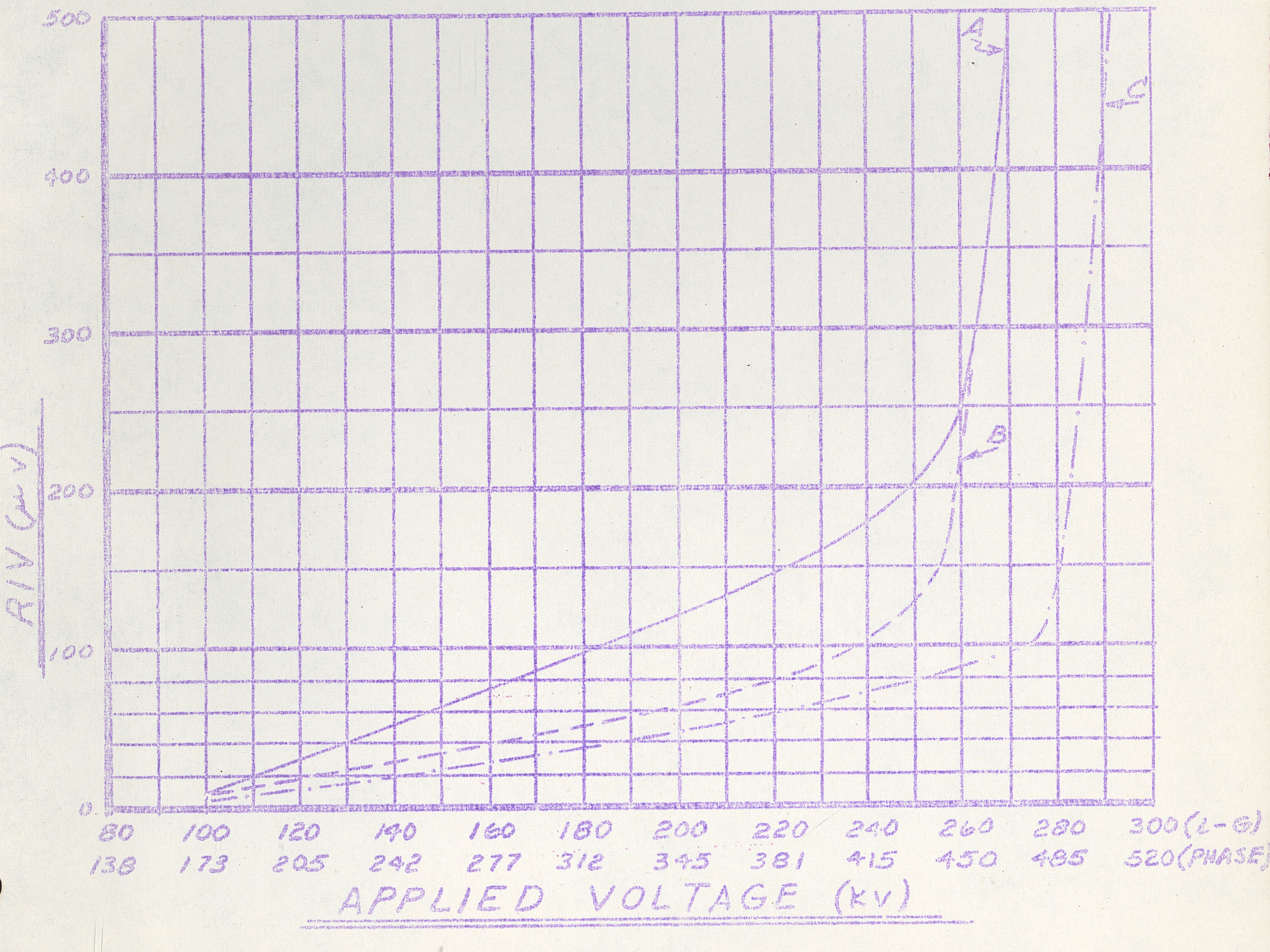
CLAMPS: LS-7-C
INSULATORS: 20- 10" x 5 3/4" Suspension
CONDUCTORS: Two 1 3/4" Tubular Horizontal Bundle 18" Spacing.

CURVE A: Plain Clamps No Shielding

CURVE B: Plain Clamps with 1 3/4" Dia. Spherical Nuts and one 6" Spherical Shield Between Insulators.

CURVE C: Same as B except 6" Spherical Shields Also attached to ends of Yoke Plate.

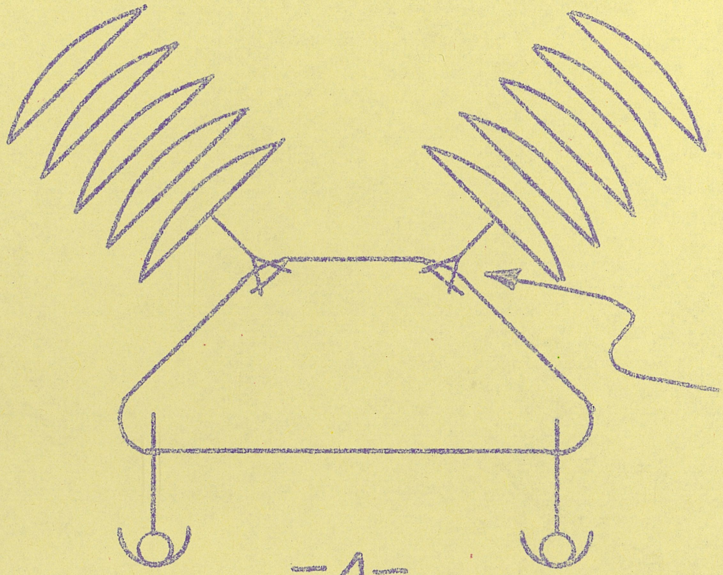
SEE ATTACHED SHEET
FOR TEST DIAGRAMS.



NOTE: Insulators attached to Yoke with "Y" Socket Clevis.

CHART IX-A

TEST DIAGRAMS



"Y" Socket Clevis

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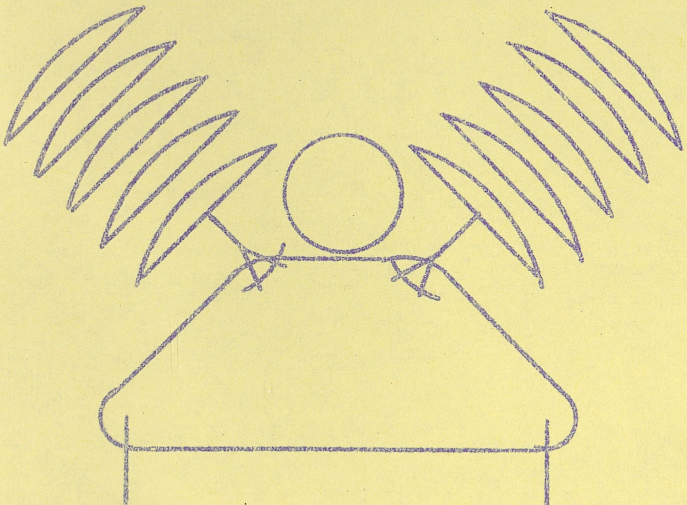

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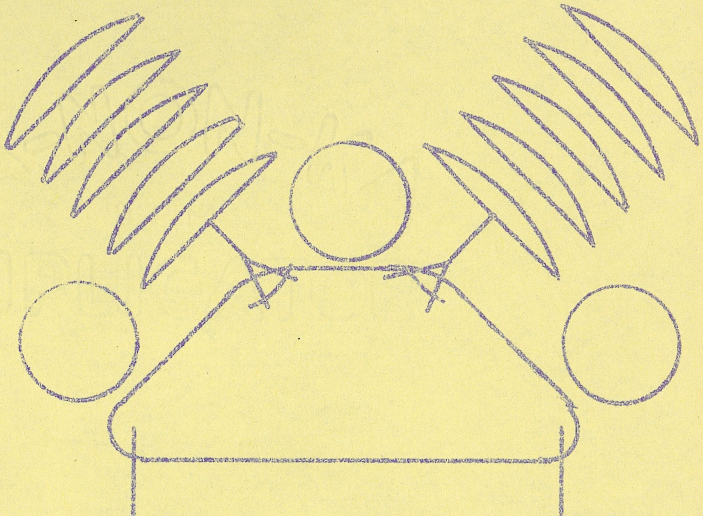

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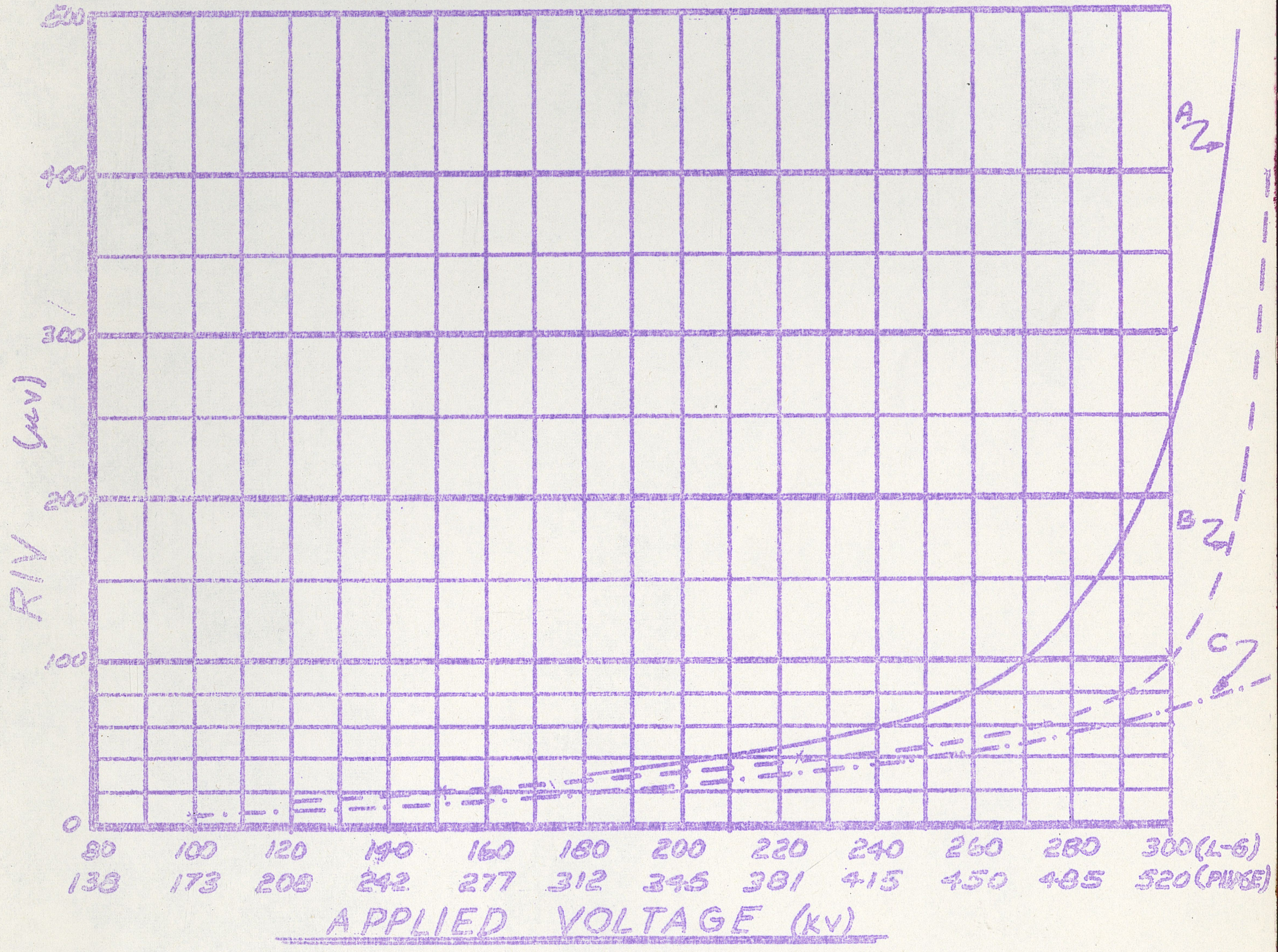
CHART IX-B

RADIO INFLUENCE VOLTAGE CHARACTERISTICS
OF
SUSPENSION ASSEMBLIES
("V" String Bundle and Large Spherical Shields)

CLAMPS:	LS-7-C
INSULATORS:	Sixteen 10" x 5 3/4" Suspension
CONDUCTORS:	Two 1 3/4" Tubular Horizontal Bundle 18" spacing
CURVE A:	Plain clamps, no shielding
CURVE B:	Plain clamps with 1 3/4" diameter Spherical Nuts and one 6" Spherical Shield between insulators
CURVE C:	Same as "B" except 6" Spherical Shields also attached to ends of Yoke Plate

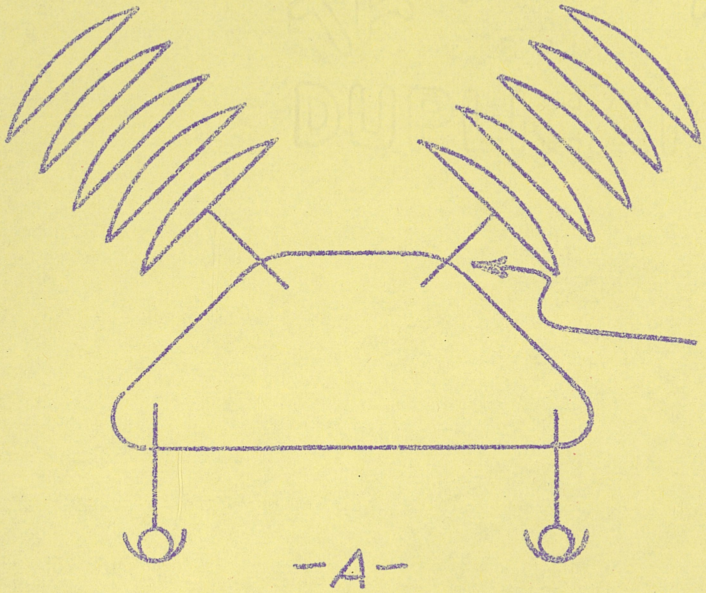
SEE ATTACHED SHEET FOR TEST DIAGRAMS



NOTE: Insulators attached to Yoke Plates with standard socket clevis.

CHART IX-B

TEST DIAGRAMS


Standard Socket Clevis

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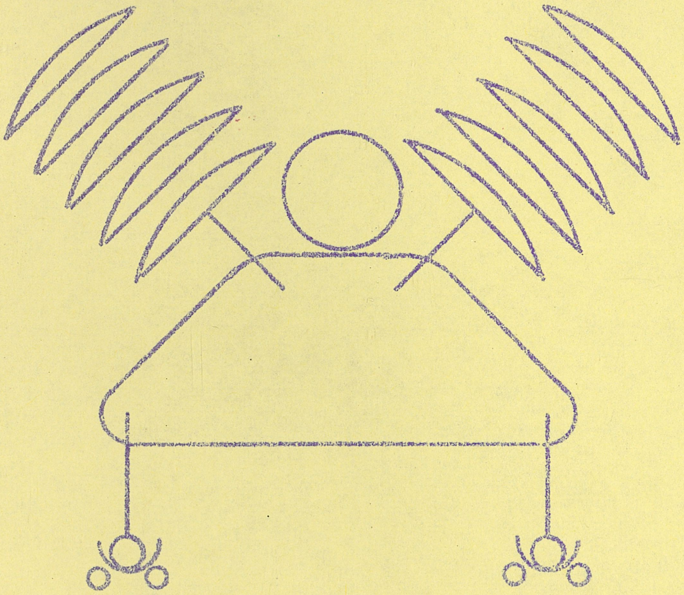
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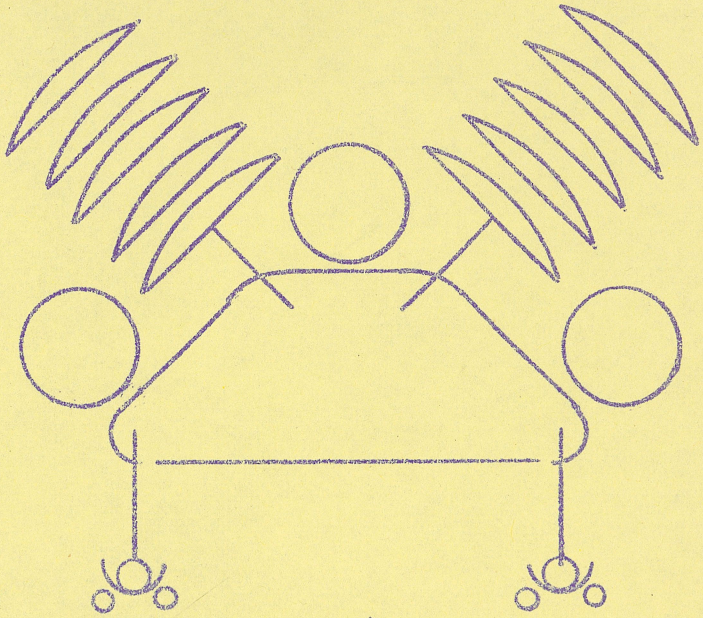
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Patents Pending

CHART X

RADIO INFLUENCE VOLTAGE CHARACTERISTICS
OF
SUSPENSION ASSEMBLIES

CLAMP:	ASC-10-C
INSULATORS:	Twenty 10" x 5 3/4" Suspension
CONDUCTORS:	Two 2 1/4" Tubular Horizontal Bundle 18" Spacing
CURVE A:	Plain clamp, no shielding
CURVE B:	Plain clamps with 1 3/4" diameter Spherical Nuts and one 6" Spherical Shield between insulators
CURVE C:	Same as "B" except Spherical Shields also attached to ends of Yoke Plate

SEE ATTACHED SHEET FOR TEST DIAGRAMS

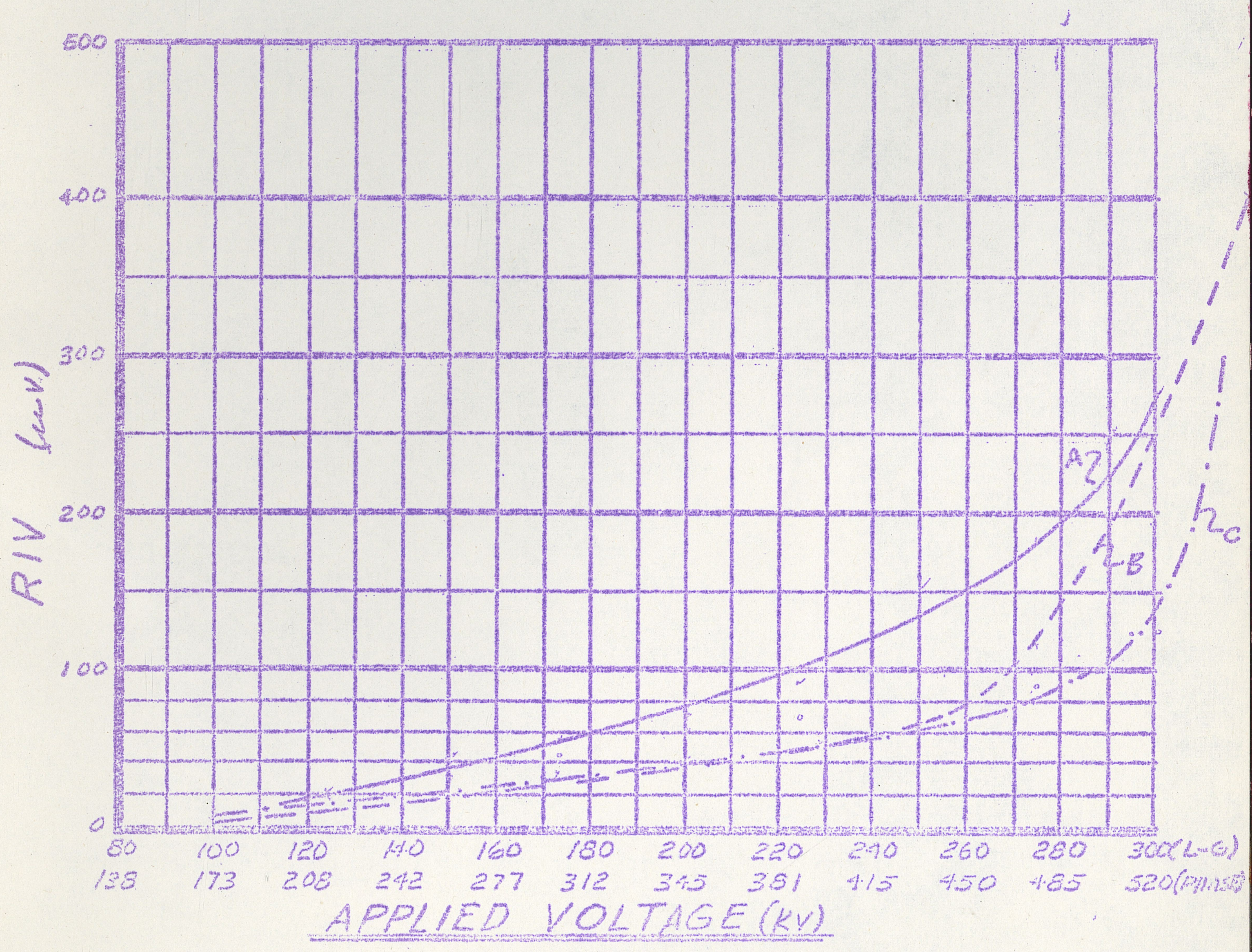
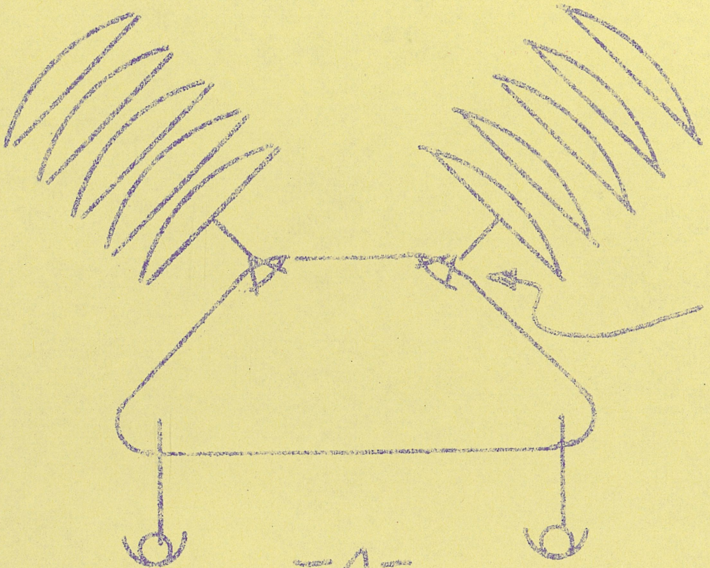


CHART X

TEST DIAGRAMS



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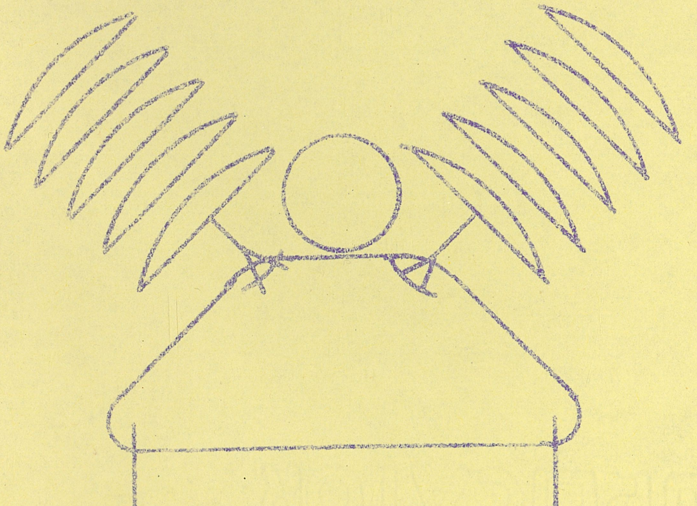
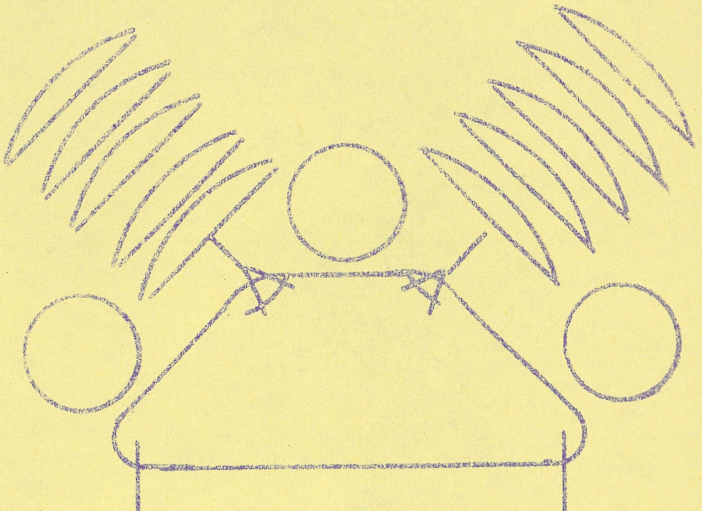


-B-



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Patents Pending

APPENDIX I

BIBLIOGRAPHY

1. A PROPOSAL FOR INTERNATIONAL STANDARDIZATION OF EHV TRANSMISSION VOLTAGES

   Philip Sporn H. P. St. Clair

   AIEE Transactions III Vol. 79 Pg. 281-4

2. THE ELECTRIC STRESS GRADING OF INSULATOR STRINGS AND THEIR RADIO INFLUENCE VOLTAGES.

   A.S. Denholm

   AIEE Transactions III Vol. 79 Pg. 167-73

3. EFFECT OF BUNDLE CONDUCTOR FIELD INFLUENCE ON EHV TRANSMISSION LINE DESIGN.

   R. H. Harmon (Ohio Brass Co.)

   Power Apparatus & Systems #54 June 1961 Pg. 316-324

4. RADIO - INFLUENCE TESTING ON 70 MILES OF 345-KV HORIZONTAL BUNDLE CONDUCTOR.

   R. E. Graham C. R. Bond

   Power Apparatus & Systems #58 February 1962 Pg. 1022

5. LEADVILLE HIGH - ALTITUDE EXTRA HIGH VOLTAGE TESTS.

   Robertson et al

   Power Apparatus & Systems #57 December 1961

6. DEVELOPMENT OF CORONA SHIELDS FOR SUSPENSION ASSEMBLIES OF BUNDLED CONDUCTOR TRANSMISSION LINES.

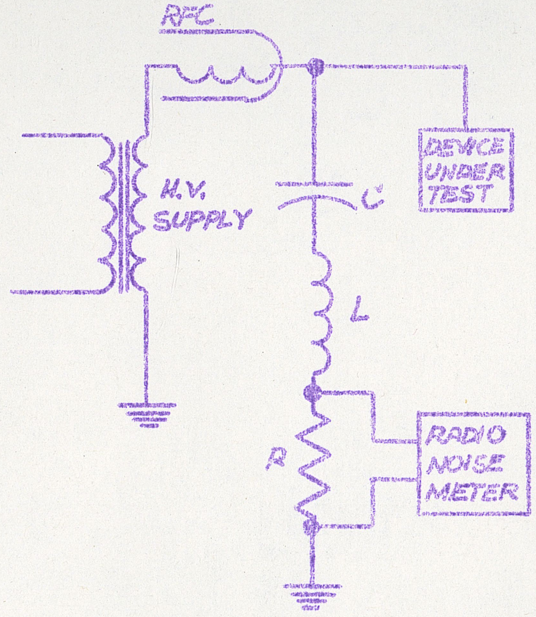
   J. Kaminski, Jr. (G.E.) AIEE Trans Paper 58-57

7. SELECTION OF SINGLE AND BUNDLE CONDUCTORS AND ACCESSORIES FOR ACCEPTABLE RADIO NOISE PERFORMANCE.

   L. O. Barthold, J. Kaminski, H. E. House, J. J. LaForest

   AIEE Conference Paper #CP-61-1099

APPENDIX II



CIRCUIT DIAGRAM

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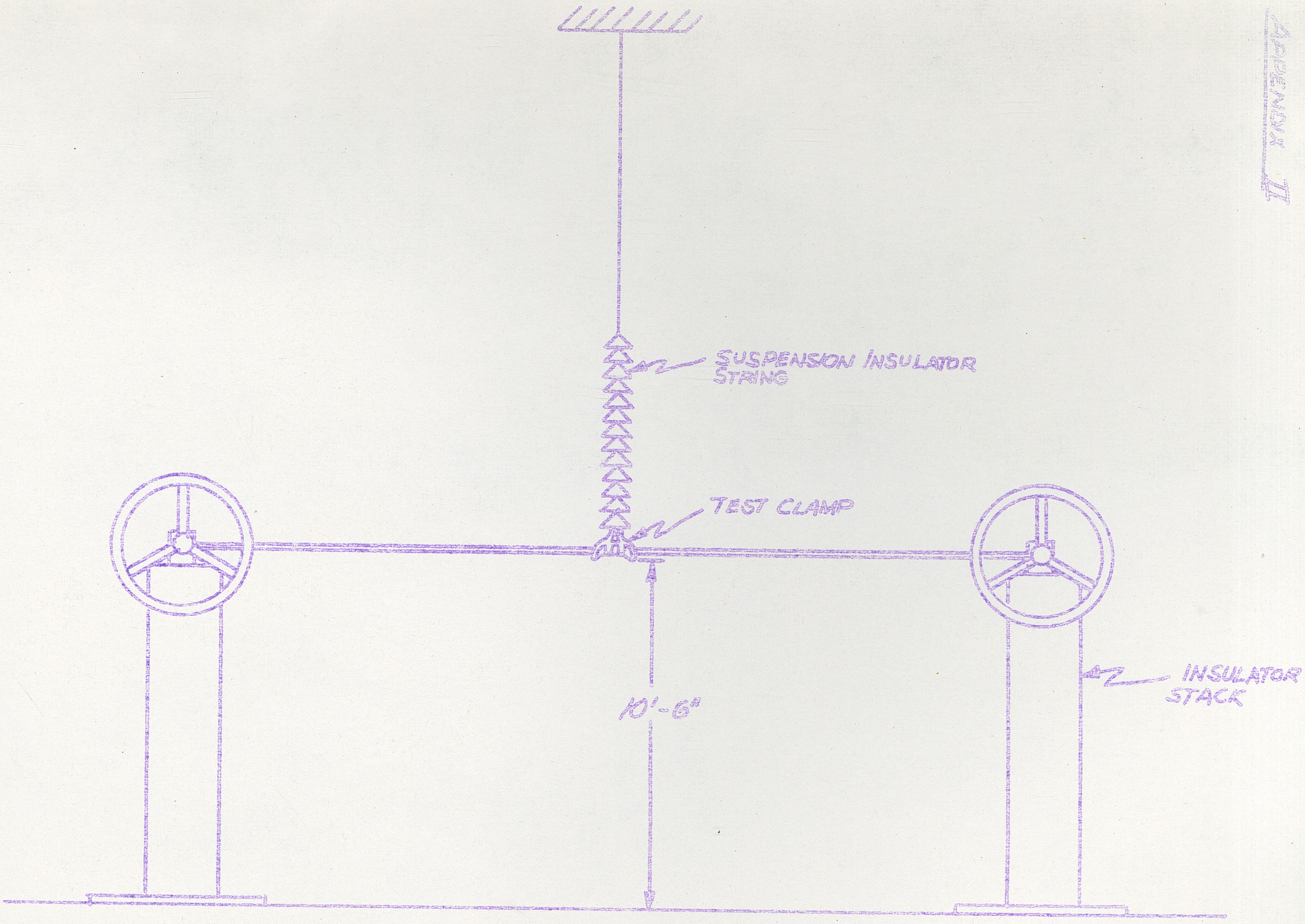
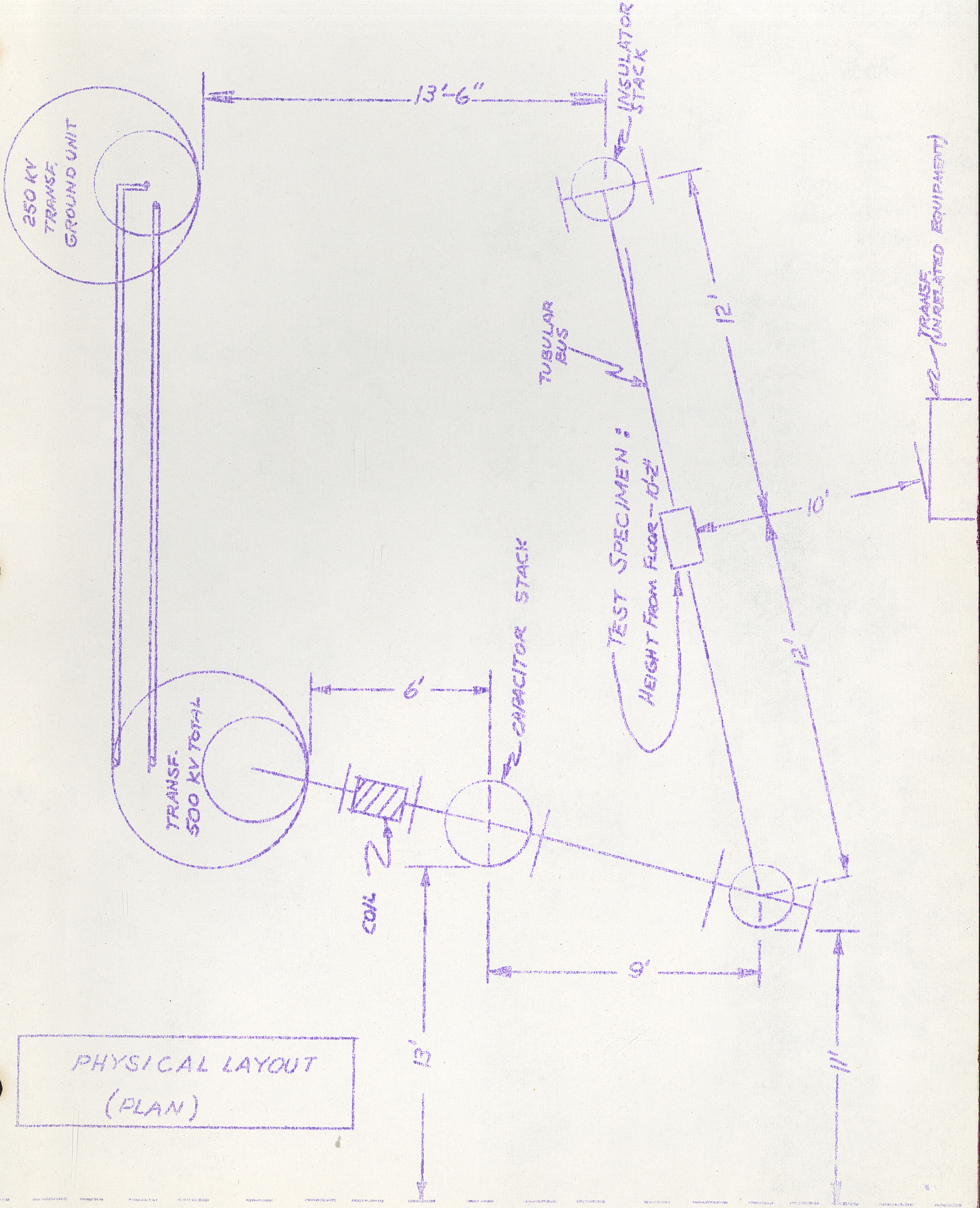


ELEVATION VIEW
OF THE
TEST SET-UP

APPENDIX II


250 KV TRANSF. GROUND UNIT
13'-6"
INSULATOR STACK
TUBULAR BUS
12'
12'
TRANSF. (UNRELATED EQUIPMENT)
10'
TEST SPECIMEN: HEIGHT FROM FLOOR - 10'-2"
CAPACITOR STACK
6'
TRANSF. 500 KV TOTAL
COIL
9'
13'
11'

PHYSICAL LAYOUT
(PLAN)

DUO-TANG
35AW
MADE IN U.S.A.